LEVEL II

UNIVERSITY OF MARYLAND

COMPUTER SCIENCE CENTER

COLLEGE PARK, MARYLAND
20742

TR-704
DAAG53-76C-0138

October, 1978

EDGE POINT LINKING USING CONVERGENT EVIDENCE

David L. Milgram
Computer Science Center
University of Maryland
College Park, MD 20742

ABSTRACT

The thinned response of an edge detector constitutes a set of edge-points lying along edges in the original image. It is possible to link each edge-point to its appropriate neighbor on either side and thus delineate these edges in the image. This is accomplished by considering all contours produced by thresholding which pass through a given edge-point. For each such contour, the edge-point nearest the given edge-point along the contour in the clockwise direction is recorded. The edge-point appearing most often as clockwise associate to the given edge-point is then assigned as the clockwise neighbor. A figure of merit based on distance, straightness and contrast is used to break any ties. The counter-clockwise neighbor is computed similarly. The resulting weighted directed graph is available for segmentation into long chains, traversal, line-fitting or template matching. The use of contours to propose pairings of edge-points is an example of the power of convergent evidence.

The support of the Defense Advanced Research Projects Agency and the U.S. Army Night Vision Laboratory under Contract DAAG-53-76C-0138 (DARPA order 3206) is gratefully acknowledged, as is the help of Kathryn Riley in preparing this paper.

1. Introduction

The importance of edge description is well documented by a rich literature. A large segment of the literature concerns the detection of points on region boundaries and the measurement of features, such as magnitude and direction, at those points. For a survey of edge detection techniques, see [1]. The edge points and feature measurements resulting from edge detection are put to many uses including threshold determination, segmentation, image matching, etc.

The grouping of edge points into higher order entities such as lines or curves has also received a good deal of attention. For an overview, see Section 8.4 of Rosenfeld [2]. Iannino and Shapiro [3] survey the Hough transform approach in which collinear points form detectable clusters and are thus associated into line segments. The sequential approach (tracking) attempts to extend the current line by affixing the best available edge point. Methods of this type are described by Montanari [4], Martelli [5] and Ashkar and Modestino [6]. A third class of methods is parallel in nature using, e.g., directed propagation to fill small gaps or relaxation to adjust incorrectly labelled edge points. See, for example, Zucker, et al. [7].

One may consider the problem of grouping edge points in a more general light. We might wish to group together those points which bound the same region in an image. However, the notion of "region" is imprecise due to conditions of poor lighting, shadows, non-planar surfaces, etc. If by a "region" we mean a "thresholdable region" then we may group together those edge points lying on the same contour after thresholding. This is the approach taken by Nakagawa and Rosenfeld [8]. However their pictorial results show that wrong associations are made when the assumption of region thresholdability is violated. The problem remains to associate edge points without requiring that the adjacent regions be thresholdable.

In [9], the author showed that the coincidence of edge points with region boundaries can serve as evidence for the presence of an object. In that method (called Superslice), an object might be evident over a range of thresholds and, for each threshold, might be represented by a different contour. Superslice selects the contour with the greatest percentage of coincident edge points. That approach relies on the convergence of evidence from two sources, thresholding and edge detection, to perform region extraction. The principle of convergent evidence is utilized in the current work to link each edge point to its best associate in the clockwise and counterclockwise direction. The algorithm which accomplishes this is called Superlink.

2. Method

To restate the problem: we are given a set of pixels (edge-points) corresponding to the locations and values of significant edge maxima in an image. Assuming that edge-points lie on edges extending some distance on either side, we wish to associate each edge-point to the appropriate edge-point on either side.

The solution is as follows: Let E be the set of edge-points and let $e \in E$. Suppose at some threshold τ, there is a connected component of above-threshold points whose boundary includes e. (We call all such boundaries "contours.") Let $e=e_1, e_2, \ldots, e_n, e_{n+1}=e$ be the succession of edge-points encountered in a clockwise traversal of the contour. We define $C(e,\tau)=e_2$ ($CC(e,\tau)=e_n$) as the clockwise (counterclockwise) neighbor of e. Each neighbor $C(e,\tau)$ delimits a path from e to $C(e,\tau)$ along a contour. At a different threshold τ', $C(e,\tau')$ might delimit a different path. We can compare paths preferring some to others based on various features and compute for each path a figure of merit. Thus, for example, short, straight paths are preferred as are those whose contrast does not vary much from one end to the other. The figure of merit used here is a weighted linear combination of length, straightness and contrast, although we recognize that many other possibilities and combinations exist. If no contour passes through e at a given threshold τ then $C(e,\tau)$, $CC(e,\tau)$ are undefined.

Consider the collection (including duplicates) of clockwise neighbors $C(e,\tau_1),\ldots,C(e,\tau_k)$ for some set of thresholds $T=\{\tau_1,\ldots,\tau_k\}$. Define $C(e)$ to be the neighbor of e occurring most often in the collection. Thus $C(e)$ is chosen as the clockwise associate of e (the counterclockwise associate $CC(e)$ is defined similarly). In the event that several edge-points occur equally often, choose as associate that edge-point contender with the highest figure of merit. It makes sense to delete any associate whose figure of merit is below some threshold, indicating the weakness of the evidence for linking the edge points.

When completed, the process has selected for each edge-point e (at most) one clockwise associate $C(e)$ and (at most) one counterclockwise associate and has computed their figures of merit. Note however that the association is not necessarily mutual (symmetric), i.e., it is not true that $CC(C(e))=e$ or that $C(CC(e))=e$. This is reasonable since it is possible for an edge-point to be in the vicinity of a corner at which three or more surfaces meet. It may also result from breaking ties or from edge-point clustering. Nonetheless, the great majority of linkings do turn out to be mutual, providing additional evidence of their correctness.

3. Implementation

Superlink has been implemented on the Univac 1108 (Exec 8) and the PDP-11/45 (UNIX) as a sequence of modules described below (Figure 1). In the first step, edge-points are located in the input image by thinning the response of an edge detector. The detector we used computed the horizontal and vertical differences of 2x2 averages. The resulting difference images were separately thinned by local non-maximum suppression. The edge-point image results from taking the maximum of the thinned horizontal and vertical responses and deleting all insignificant edge responses (≤ 1).

Prior to contour extraction, it is necessary to determine the set of gray levels T at which to threshold the input image. Naturally, T can consist of the whole gray-level range in the input image. However, this can be expensive. Frequently, one has knowledge of the likely gray level range of the edge-points of interest. For example, in a two population image (object/background) the range between the modes would define T. Alternatively, one could sample the gray level range choosing every other gray level, etc. The danger in any scheme which skips gray levels is that all contours at the ignored gray level thresholds as well as the possible pairings of edge-points along these contours are lost. Thus less evidence is available when choosing associates, which makes the selections more dependent on figure of merit (a distinctly weaker criterion than "most often occurring edge-point"). Nonetheless, the degradation incurred by deleting gray levels is gradual as is discussed in the next section.

Once a set of gray level thresholds is chosen, the contours are extracted [10] and stored in Freeman chain code. This takes one pass over both images (gray level and edge-point) for each of the thresholds. The accumulated chain-encoded contours are stored on disk. Next, the disk file is read contour by contour. For each contour, the sequence of edge-points is noted and the figure of merit is computed for each adjacent pair in the sequence. The coordinates of each pair of edge-points and its figure of merit are then written to a file. The file of edge-point pairs is quite large (40,000 pairs for a 256^2 image using 12 thresholds). It is sorted (using a system sorting package) so that all pairs containing a given edge-point are in contiguous sequence.

The sorted file is a sequence of edge point lists. Each edge-point list is the set of pairs for a given edge-point. Once it is read, it is straightforward to compute the most numerous associate or, in the event of a tie, the best figure of merit. The (edge-point, associate) pair is then written to a separate file. Finally, the associates file is converted to an image by taking each associated pair of coordinate points and drawing a straight line in the image to signify their linkage. This last step is convenient for display purposes;

however, the use of a straight line to join edge-points only serves as an approximation to the contour segment which actually bridges the two points.

4. Results

The algorithm as described in the previous section has been run using a variety of input images. Figure 2 shows several FLIR images of military vehicles and illustrates the extracted edge-points. Figure 3 displays the edge-points and their links. Links whose figures of merit were below a preset threshold are not shown. Our experience has been that selecting a threshold for the figure of merit is difficult unless a very generous one is used, as was done here. Normally, all but about 3% of the proposed links appear to be justifiable. Of course, some links are the result of more evidence than others and the figure of merit attempts to capture this. Thus the underlying data structure is a weighted directed graph, with the figure of merit corresponding to the weight.

A portion of an image of automotive parts from a GM data base [11] shows the effect of thresholding the figure of merit (Figure 4). As more links are deleted, some "obviously correct" linkages disappear while others which are somewhat more dubious remain. A blow-up of the upper-right portion (Figure 5) shows that where the edge-points form a staircase pattern, the linkages form small loops. Small loops may also result from the linkages of isolated points. This demonstrates as well that the process which creates edge-points must locate the points accurately, thin them sufficiently, and discard those deemed not to correspond to actual edges. Figure 6 shows the effect of thresholding the edge-point population on the linkages produced.

It was mentioned previously that the most effective linkages are produced when all gray level thresholds are employed but that degradation is graceful as gray levels are omitted. Figure 7 illustrates the effect of retaining only every other gray level. Figure 8 shows another example of the GM data base along with the resulting linkages based on every other gray level.

5. Conclusions

The Superlink algorithm joins edge-points based on thresholding evidence. By and large, its proposed linkages are reasonable. Much work, however, remains. First, the current figure of merit, while well-founded, is heuristic and could benefit from further analysis. For example, no notice is taken currently of mutual linkages; yet, clearly, this is powerful evidence that the linkage is legitimate. Secondly, the choice of edge points depends on the type of edge detector, the method of thinning and the elimination of noise points. Third, the steps making up Superlink can be consolidated and the processes made to run much more efficiently. Finally, new algorithms are needed to track the linkage data structure and to extract consistent boundaries.

References

1. Davis, L.S. "A survey of edge detection techniques," Comp. Graphics and Image Proc., Vol. 4, No. 3, 1975, 248-270.

2. Rosenfeld, A. and A. Kak. Digital Picture Processing, New York, 1976.

3. Iannino, A. and S. Shapiro. "A survey of the Hough transform and its extensions for curve detection," Proc. of IEEE Conf. on Patt. Rec. and Image Proc., May 1978, Chicago, IL, 32-38.

4. Montanari, U. "On the optimum detection of curves in noisy pictures," Comm. of the ACM, Vol. 14, No. 5, 1971, 335-345.

5. Martelli, A. "An application of heuristic search methods to edge and contour detection," Comm. of the ACM, Vol. 19, No. 2, 1976, 73-83.

6. Ashkar, G. and J. Modestino. "The contour extraction problem with biomedical applications," Comp. Graphics and Image Proc., Vol. 7, No. 3, 1978, 331-355.

7. Zucker, S., Hummel, R., and A. Rosenfeld. "An application of relaxation labelling to line and curve enhancement," IEEE Trans. Computers, Vol. 26, 1977, 393-404; 922-929.

8. Nakagawa, Y. and A. Rosenfeld. "Edge/border coincidence as an aid in edge extraction," Univ. of Md. Comp. Sci. Ctr. TR-647, March 1978.

9. Milgram, D. "Region extraction using convergent evidence," Univ. of Md. Comp. Sci. Ctr. TR-674, June 1978.

10. Milgram, D. "Constructing trees for region description," Univ. of Md. Comp. Sci. Ctr. TR-541, June 1977.

11. Baird, M.L. "A computer vision data base for the 'industrial bin of parts' problem," Research Publication GMR-2502, Research Laboratories, General Motors Corp., Warren, MI, August 1977.

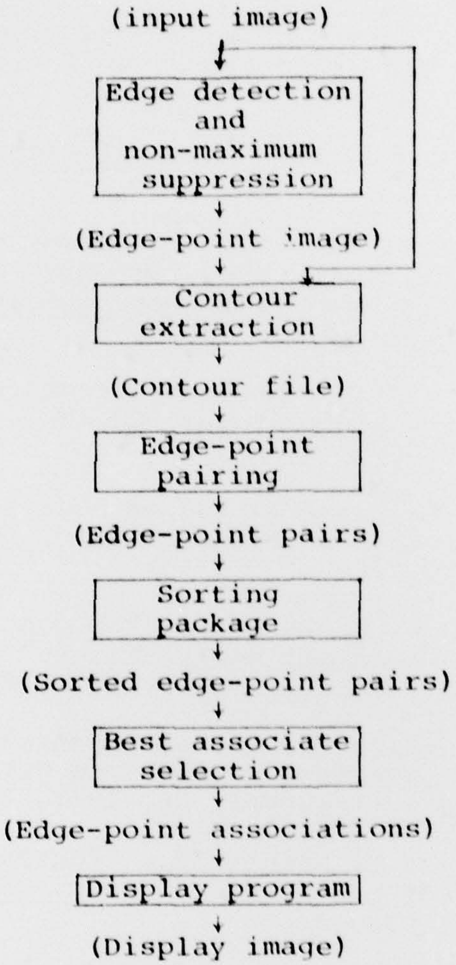
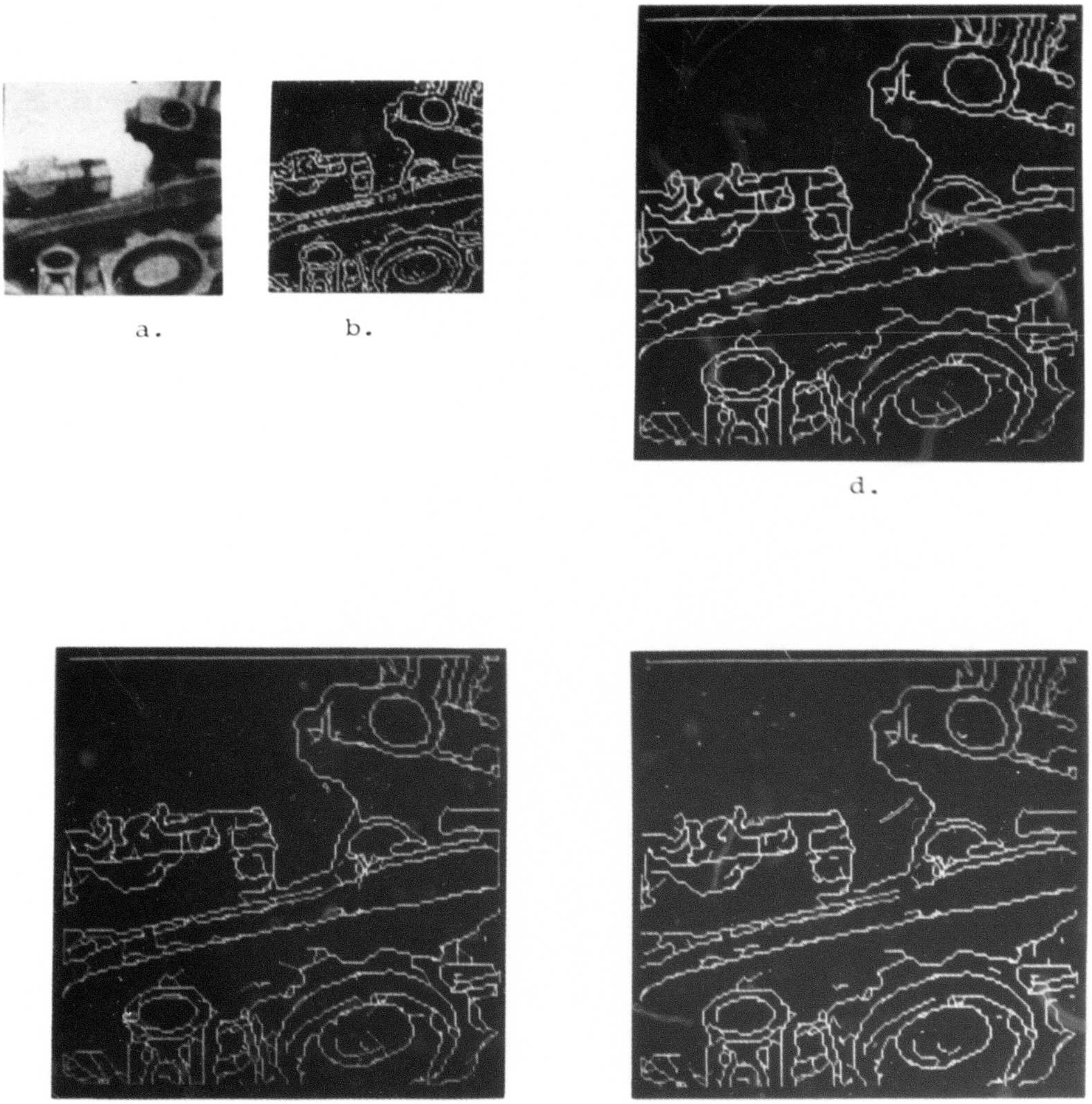


Figure 1. Superlink processing steps



a. b. d. c. e.

Figure 4. Effects of thresholding the figure of merit
a. Original gray level window
b. Edge-point image
c. Edge-point associates, threshold at .4
d. Same as c., threshold at .5
e. Same as c., threshold at .6

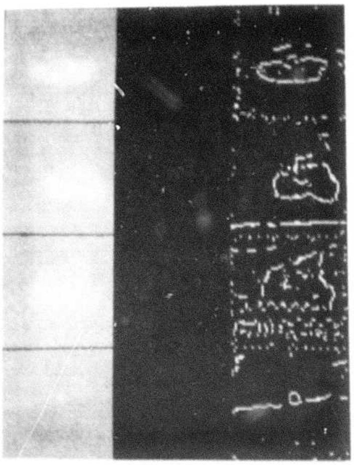
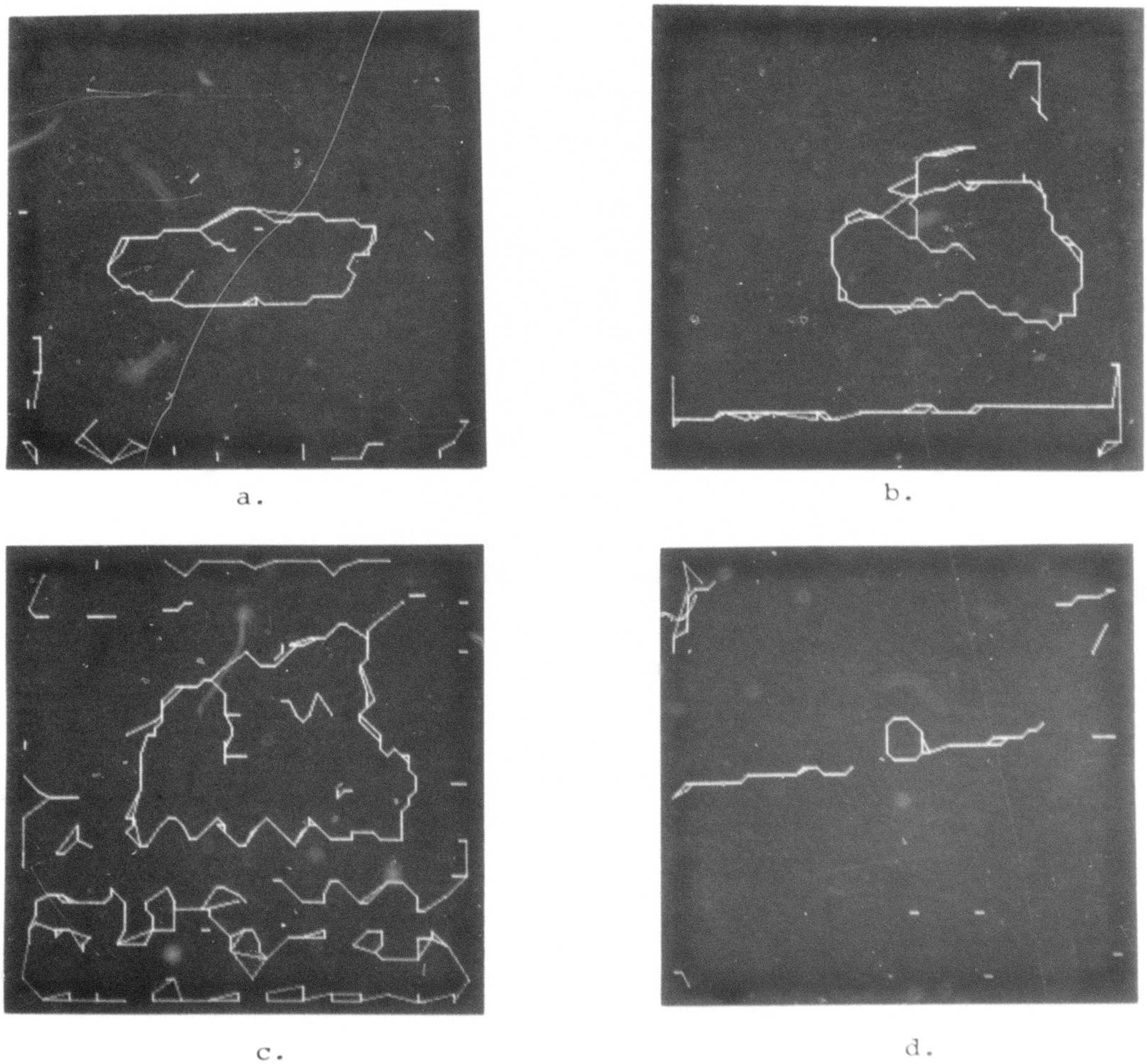


Figure 2. Gray scale windows and edge-point windows of four tanks from the NVL Data Base.



a. b.

c. d.

Figure 3. Edge-point associates of windows in Figure 2.

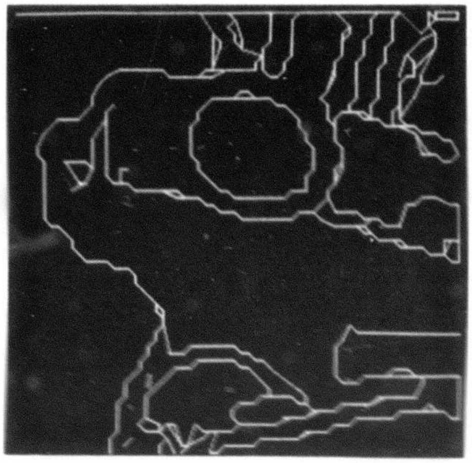
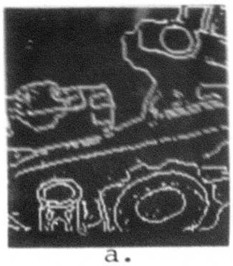
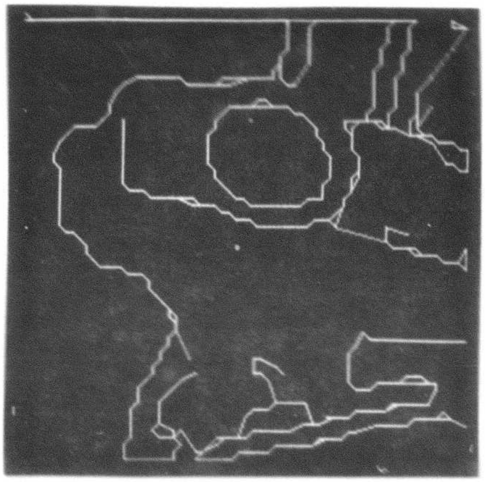


Figure 5. Blowup of upper-right corner of Figure 4c to display the effects of thinning errors



a.



b.

Figure 6. The effects of edge-point selection
a. Edge point subset of Figure 4b.
b. Edge point associates for upper-right quadrant

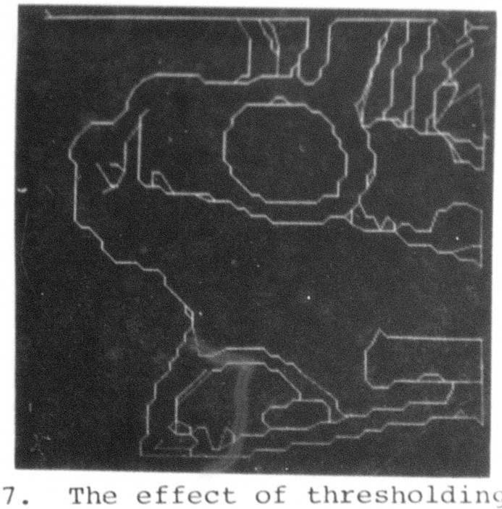
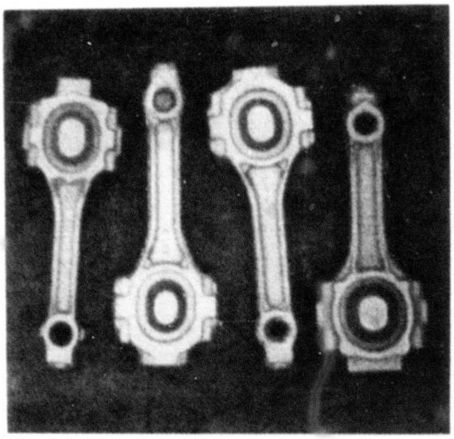
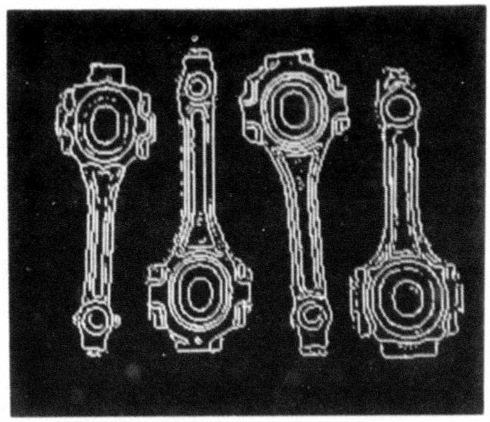


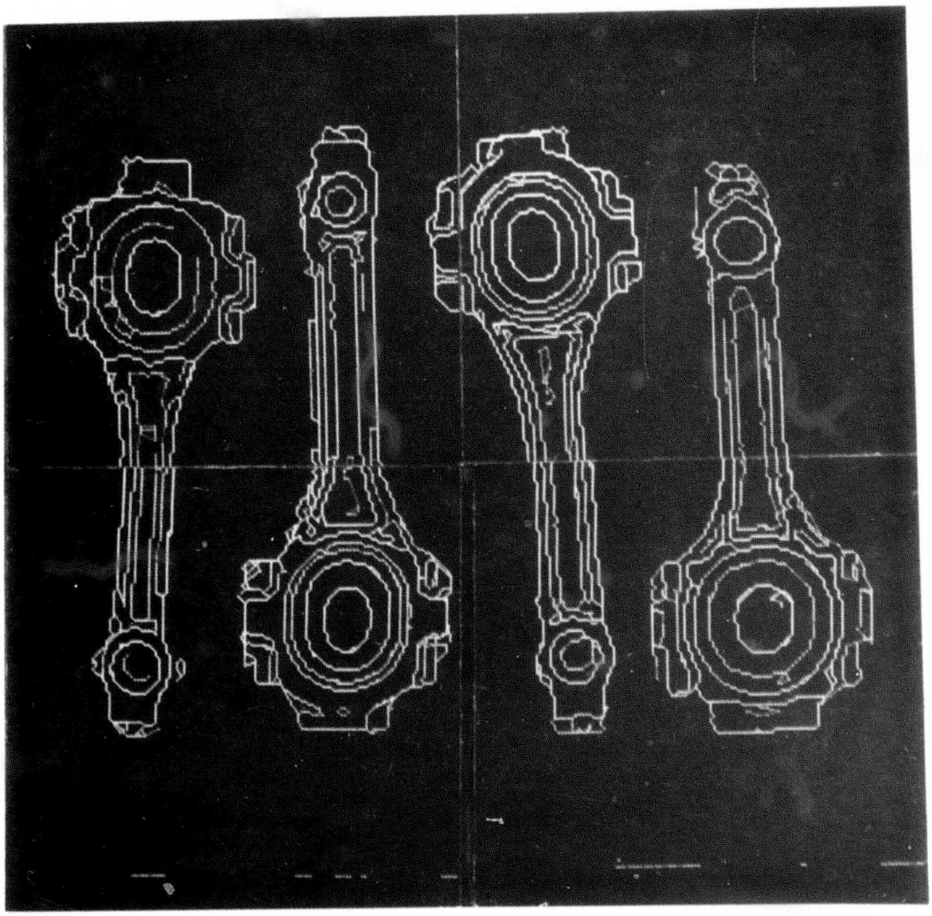
Figure 7. The effect of thresholding at even gray levels only. Compare with Figure 5.



a.



b.



c.

Figure 8. Another image from the GM Data Base
a. Original
b. Edge-point image
c. Edge-point associations

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REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) EDGE POINT LINKING USING CONVERGENT EVIDENCE.	5. TYPE OF REPORT & PERIOD COVERED (9) Technical rept.,
	6. PERFORMING ORG. REPORT NUMBER (14) TR-704
7. AUTHOR(s) (10) David L. Milgram	8. CONTRACT OR GRANT NUMBER(s) (15) DAAG53-76C-0138
9. PERFORMING ORGANIZATION NAME AND ADDRESS Computer Science Ctr. University of Maryland College Park, MD 20742	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 20
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Night Vision Lab. Ft. Belvoir, VA 20060	12. REPORT DATE (11) October, 1978
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (15) DAAG53-76-C-0138 DARPA Order-3206	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pattern recognition
Image processing
Edge detection
Thresholding
Contour extraction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The thinned response of an edge detector constitutes a set of edge-points lying along edges in the original image. It is possible to link each edge-point to its appropriate neighbor on either side and thus delineate these edges in the image. This is accomplished by considering all contours produced by thresholding which pass through a given edge-point. For each such contour, the edge-point nearest the given edge-point along the contour in the clockwise direction is recorded. The edge-point appearing most often as → next page

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clockwise associate to the given edge-point is then assigned as the clockwise neighbor. A figure of merit based on distance, straightness and contrast is used to break any ties. The counter-clockwise neighbor is computed similarly. The resulting weighted directed graph is available for segmentation into long chains, traversal, line-fitting or template matching. The use of contours to propose pairings of edge-points is an example of the power of convergent evidence.